NEUTRON SPECTRUM AND DOSE WITH ANN

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ABSTRACT

Artificial neural networks have been applied to unfold the neutron spectra and to calculate the effective dose, the ambient equivalent dose, and the personal dose equivalent for ^{252}Cf, ^{239}PuBe, and ^{241}AmBe neutron sources. The count rates that these neutron sources produce in a Bonner Sphere Spectrometer with a ^{6}LiI(Eu) were utilized as input in both artificial neural networks. Spectra and the ambient dose equivalent were also obtained with BUNKIUT code and the UTA4 response matrix. With both procedures spectra and ambient dose equivalent agrees in less than 10%. The Artificial neural network technology is an alternative procedure to unfold neutron spectra and to perform neutron dosimetry.

INTRODUCTION

The measurement of the intensity of a radiation field with respect to certain quantity is a central role in radiation spectrometry having, as a final result, the radiation spectrum that helps to characterize the radiation field. (1, 2)

Regardless how neutrons are produced they have a wide energy range extending from few thousandths of eV to several hundreds of MeV. Also, they are in a broad variety of energy distributions, named neutron-fluence spectrum or simply neutron spectrum, $\Phi_E(E)$. (2, 3)

The Bonner sphere spectrometer, BSS, or multisphere neutron spectrometer, is a set of high-density polyethylene spheres with a thermal neutron detector in their centre that is utilized to obtain, through an unfolding process, the $\Phi_E(E)$. Each sphere-detector combination has a unique response, the whole set of responses is the response matrix, $R_\Phi(E)$.

Unfolding process involves solving Equation 1, which is a Fredholm integral equation of the first kind.

$$C_i = \int R_{\Phi,i}(E)\, \Phi_E(E)\ dE \qquad (1)$$

Here, C_i is the count rate measured with the i^{th} sphere-detector combination. Response functions have poor energy resolution and are not fully linearly independent of each other. The spectrum is defined in a large number of energy groups in comparison to the number of spheres used in the spectrometer thus; Equation 1 is an ill-conditioned problem (4). Total fluence is obtained integrating the $\Phi_E(E)$ for all energies as shown in Equation 2.

$$\phi = \int \Phi_E(E)\ dE \qquad (2)$$

Once the $\Phi_E(E)$ is obtained the required dose, Δ, is obtained using Equation 3.

$$\Delta = \int \delta_\Phi(E)\, \Phi_E(E)\ dE \qquad (3)$$

Here, $\delta_\Phi(E)$ are the fluence-to-required dose conversion coefficients (5). Therefore, the main problem is to solve Equation 1 and several procedures are utilized (4).

In the brain, a neural network is a massively parallel distributed processor with a natural propensity for saving experiential knowledge, previously acquired through a learning process, making it available for latter use. The Artificial Neural Networks, ANNs, have been proposed to emulate this feature from brain's behaviour. (6)

The mathematical models used to design an ANN have at least three layers, the input, hidden and the output. Each layer has several process units, the neurons, which are connected through synaptic weights where the knowledge is stored. The activation of a neuron depends on the given weight of the synapses that are appraised through the activation functions. (7, 8)

The ANN learning is the adaptation process to the training data. The training has the purpose of selecting the weights that adapts better to the network in relation to training data. During ANN training a set of data, with input and output information, is utilized and the synaptic weights are adjusted until, at some point, the pattern between input and output data is accomplished.

The ANN technology has been utilized to unfold the neutron spectrum, and with this the neutron dose has been estimated (4, 7, 8). Also, The ANNs have been applied to obtain directly the neutron doses without the need of neutron spectrum information (5). In all these applications only the count rates obtained with a BSS are required.

In this work the ANN technology has been utilized to unfold the neutron spectrum and to determine the neutron doses of ^{252}Cf, ^{239}PuBe, and ^{241}AmBe neutron

sources, using the count rates measured with a BSS. These results were compared with spectra and the H*(10) obtained with BUNKIUT code.

MATERIALS AND METHODS

Two different ANNs were designed and trained, the first to perform the neutron spectrometry and the second to calculate thirteen dosimetric quantities. The lethargy spectra were taken from the compilation made by the International Atomic Energy Agency (9) and were converted to energy spectra. With the MCNP 4C code (10), the spectra were re-binned from their original energy distribution defined in 60 energy groups to 31 energy groups (11), which is the energy structure utilized in BUNKIUT code (12). For each spectrum the E_{AP}, E_{PA}, E_{RLAT}, E_{LLAT}, E_{ROT}, E_{ISO}, H*(10), $H_{p,s}(10,0^o)$, $H_{p,s}(10,15^o)$, $H_{p,s}(10,30^o)$, $H_{p,s}(10,45^o)$, $H_{p,s}(10,60^o)$, $H_{p,s}(10,75^o)$ were calculated using the fluence-to-dose conversion coefficients from ICRP 74 (13).

The re-binned spectra were utilized, together with UTA4 matrix response (14), to calculate their respective count rates produced in the Bonner spheres whose diameters are 0, 5, 7.62, 12.7, 20.32, 25.4 and 30.48 cm.

One hundred seventy seven neutron spectra, their doses and their respective BSS count rates were utilized to train and test both ANNs. From the available set of data the 10% was randomly selected and isolated from the whole set to test the ANN, the remainder was left for training purposes. Both ANNs were trained and tested using MATLAB® software[1]. Topology of ANN for spectrometry was 7:140:500:140:70:27, where each number is the amount of neurons in each layer. For dosimetry the ANN topology was 7:140:200:401:140:13. Both ANNs were feed-forward with

[1] MATLAB is a trade mark of The MathWorks, Inc.

backpropagation algorithm and variable learning rate.(15) After training the ANNs' performance were verified using the data set that was not utilized for training purposes.

The BSS was utilized to obtain the count rates produced by ^{252}Cf, ^{239}PuBe and ^{241}AmBe. Their respective activities were 4.34 x 10^8, 1.85 x 10^{11} and 3.7 x 10^9 Bq. During BSS measurements the source-to-spectrometer distance was 120, 100 and 50 cm for ^{252}Cf, ^{239}PuBe and ^{241}AmBe respectively. The count rates were utilized to unfold the neutron spectra using BUNKIUT code and UTA4 response matrix; the neutron spectra was utilized to estimate the H*(10). Neutron spectra were also unfolded with the ANN designed for spectrometry, and the dosimetric quantities were calculated using the ANN designed for dosimetry.

RESULTS AND DISCUSSION

In figure 1 is shown the neutron spectrum of ^{252}Cf obtained with BUNKIUT code and the ANN for spectrometry. Here can be noticed that both results have good agreement. The total fluence is 193 ± 3% cm^{-2}-s^{-1} and 191 ± 3% cm^{-2}-s^{-1}, for spectrum obtained with BUNKUT and the ANN respectively. The uncertainty was taken from the uncertainty of count rates, therefore in both cases no uncertainties were assigned to the unfolding process.

In figure 2 is shown the ^{239}PuBe neutron spectrum unfolded with BUNKIUT and the spectrum unfolded with the ANN trained to perform neutron spectrometry. The shape of both spectra looks alike. The total fluence is 121 ± 5% cm^{-2}-s^{-1} and 128 ± 5% cm^{-2}-s^{-1}, for spectrum obtained with BUNKUT and the ANN respectively. Uncertainties were assigned from those from BSS count rates and no uncertainties were assigned to the unfolding process.

The ^{241}AmBe neutron spectra obtained with BUNKIUT and the ANN for spectrometry is shown in figure 3. It can be noticed that both are similar. The total fluence for both spectra is 8 ± 5% cm^{-2}-s^{-1}. As in both previous cases no uncertainties were assigned to the unfolding process and the 5% comes from the BSS count rates.

The presence of epithermal and thermal neutrons in the spectra is due the room return effect (16). In all the cases the ANN for spectrometry was able to unfold the neutron spectra using only the BSS count rates.

The dosimetric quantities obtained with the ANN for dosimetry is shown in Figure 4. The neutron fluence-to-ambient dose equivalent factors, h*(10), obtained with the ANN were 281, 270, and 322 pSv-cm^2. With BUNKIUT these values were 296, 265 and 314 pSv-cm^2 for ^{239}PuBe, ^{241}AmBe, and ^{252}Cf respectively. The differences go from 1.7 to 5%. According to IAEA (9) the h*(10) for ^{241}AmBe is 395 pSv-cm^2 while for ^{252}Cf is 380 pSv-cm^2, these values are assuming point-like sources in vacuum. In this work h*(10) was larger for ^{252}Cf than ^{241}AmBe due to the changes in the neutron spectra due to experimental conditions.

The H*(10) calculated with the ANN were 3.593 x 10^4, 2.272 x 10^3, and 6.153 x 10^4 pSv, with BUNKIUT these values are 3.573 x 10^4, 2.192 x 10^3, and 6.050 x 10^4 pSv for ^{239}PuBe, ^{241}AmBe and ^{252}Cf respectively. The differences between those values go from 0.6 to 3.6%.

Considering the uncertainties of the BSS count rates, the differences noticed in h*(10) and H*(10) are not relevant. The ANN for dosimetry was able to calculate the neutron doses using only the measured BSS count rates.

CONCLUSIONS

Two ANNs, one for spectrometry and other for neutron dosimetry, were utilized to unfold the neutron spectra and to estimate the dosimetric features of, ^{252}Cf, ^{239}PuBe, and ^{241}AmBe neutron sources. Spectra and doses were also calculated using the BUNKIUT code. Results obtained with both procedures are in agreement. The ANN technology has been successfully applied utilizing as input the BSS count rates. Therefore this technology is an alternative procedure for neutron spectrometry and dosimetry.

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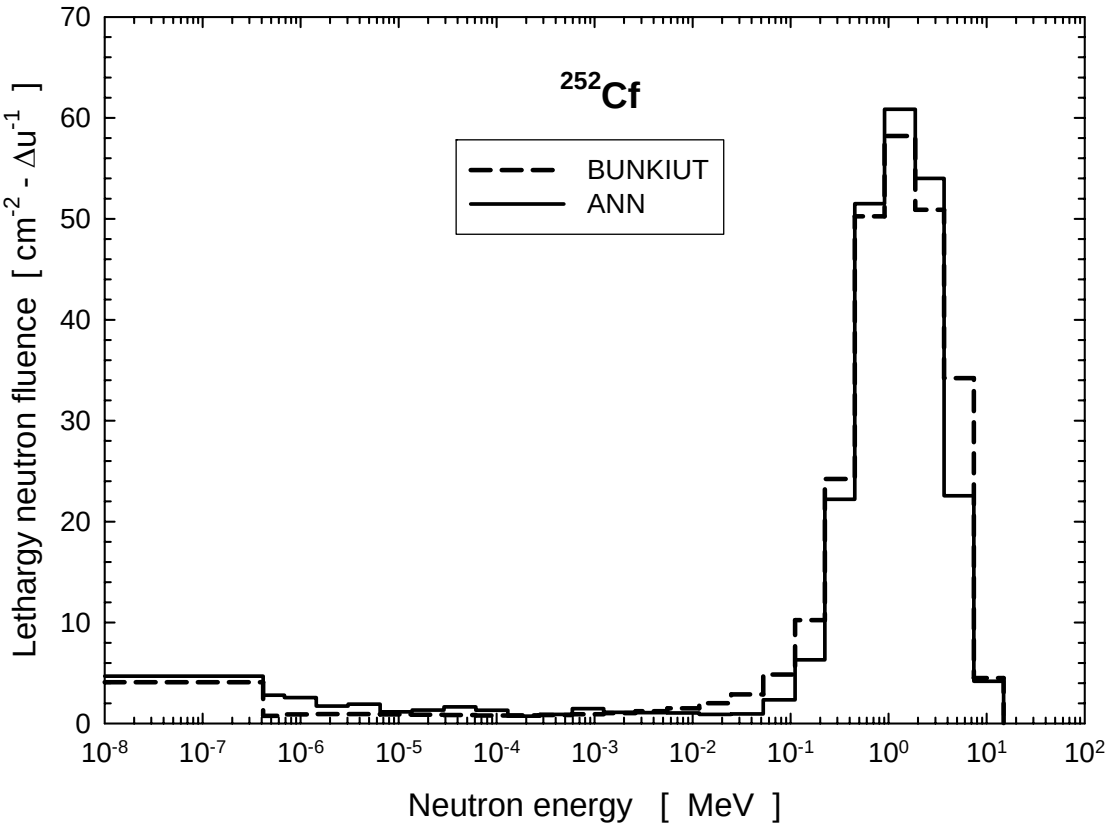

Neutron spectrum and dose with ANN
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Figure 1

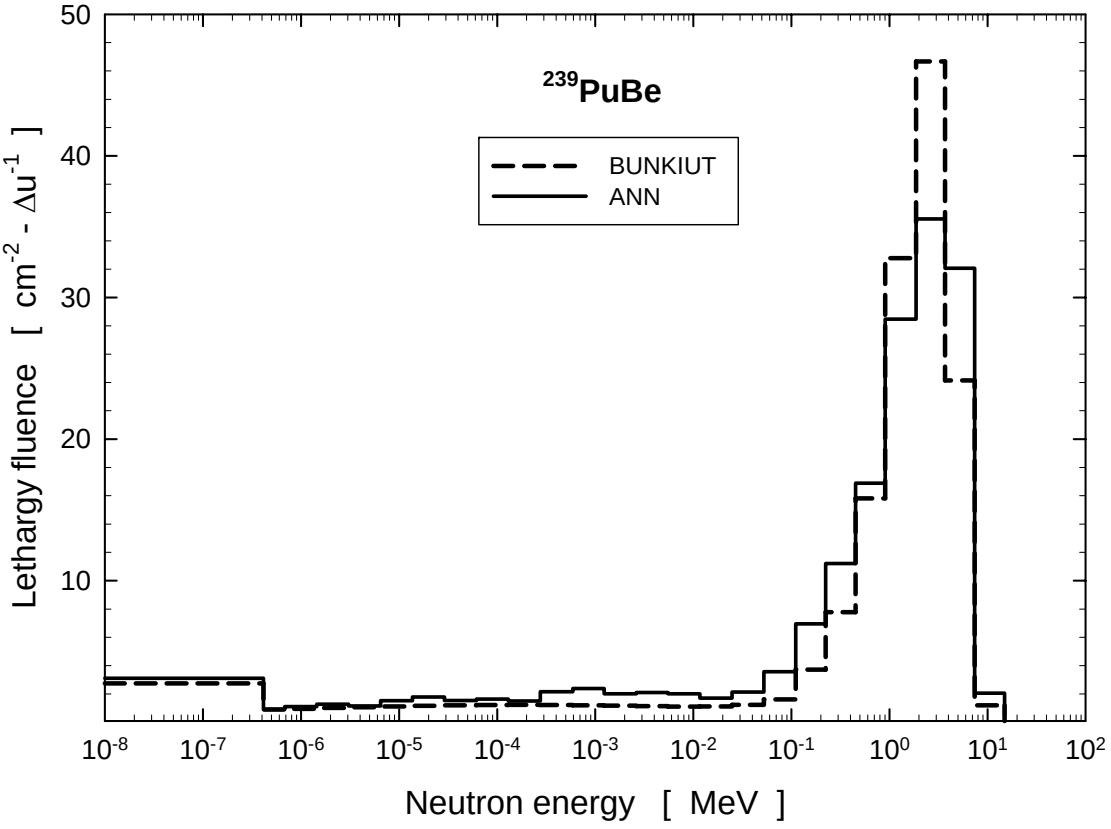

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Figure 2

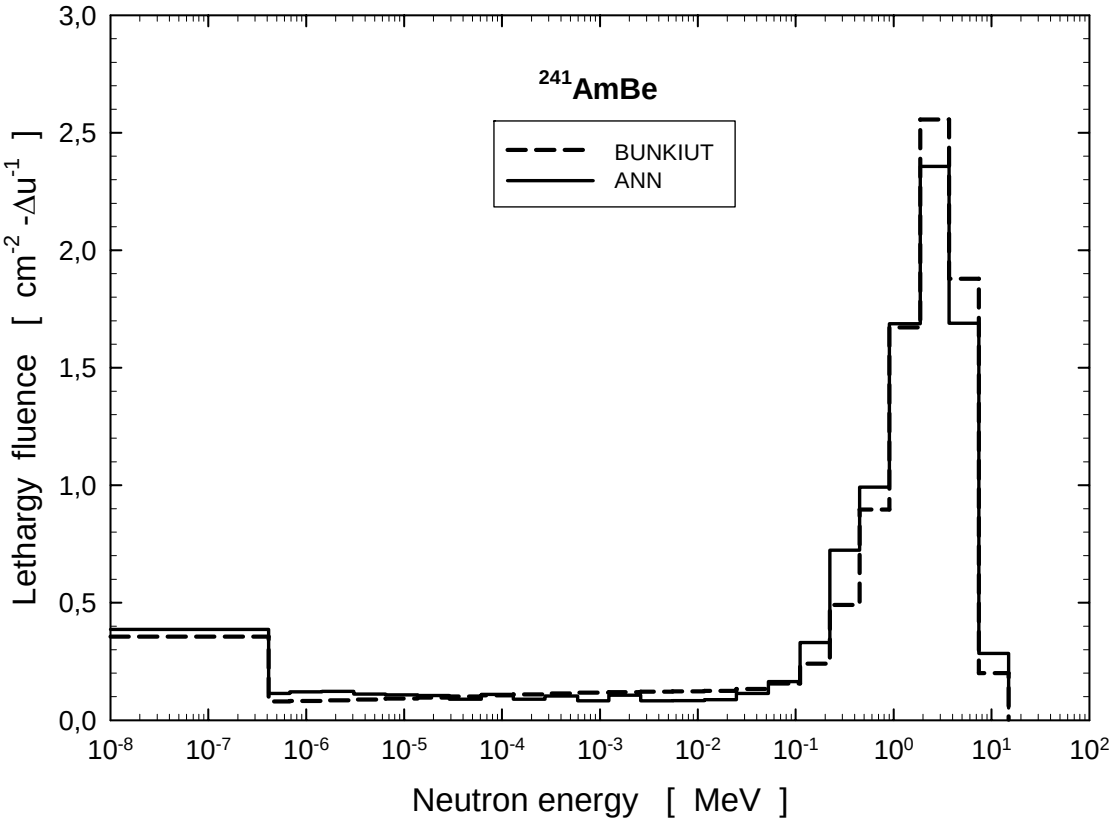

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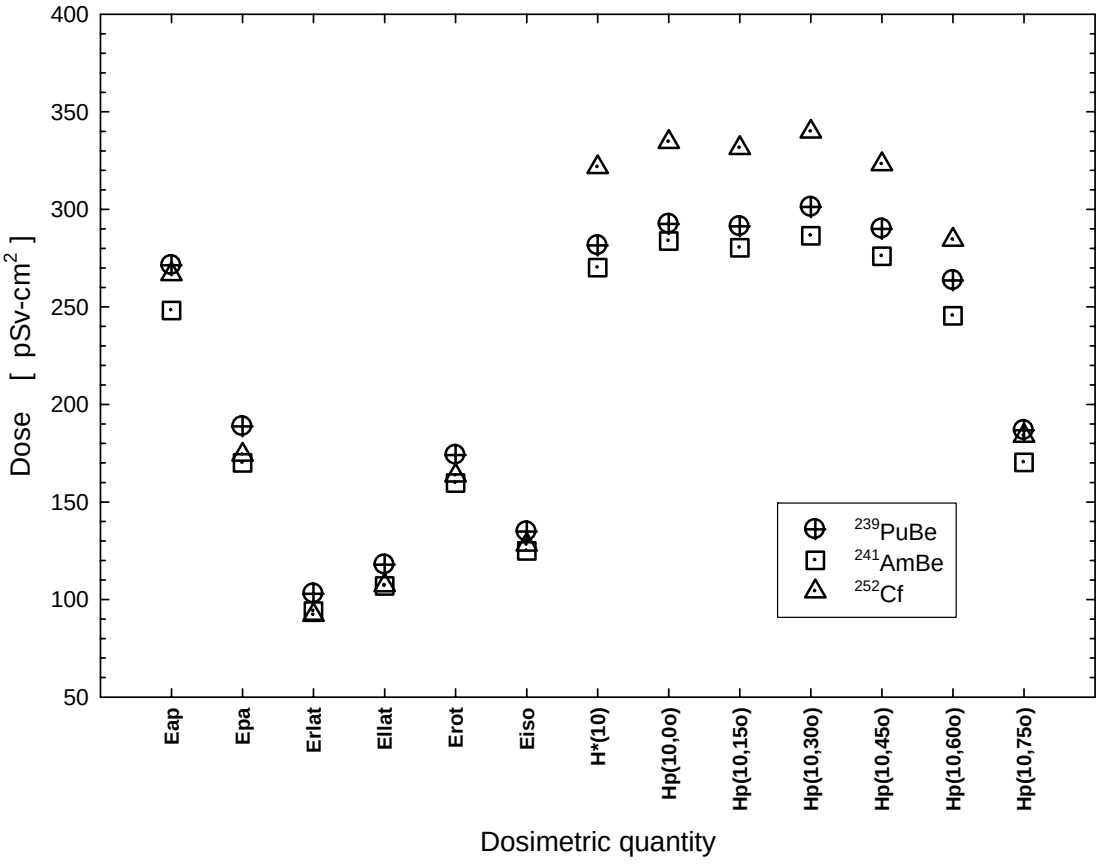
Figure 3.



Neutron spectrum and dose with ANN
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Figure 4.

Figure captions

Figure 1.- Neutron spectrum of ^{252}Cf source.

Figure 2.- Neutron spectrum of ^{239}PuBe source.

Figure 3.- Neutron spectrum of ^{241}AmBe source.

Figure 4.- Dosimetric quantities for ^{239}PuBe, ^{241}AmBe and ^{252}Cf.